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Abstract This paper investigates the determinants of rapeseed hail insurance and chemical input decisions using individual panel data set of French farms covering the period from 1993 to 2004. Economic theory suggests that insurance and prevention decisions are not independent due to risk reduction and/or moral hazard effects. We propose a theoretical framework that integrates two statistically independent sources of risk faced by farmers of our sample –hail risk and pest risk. Statistical tests confirm that chemical and insurance demands are endogenous to each other and simultaneously determined. An econometric model involving two simultaneous equations with mixed censored/continuous dependent variables is thus estimated for rapeseed. Estimation results show that rapeseed insurance demand has a positive and significant effect on pesticide use and vice versa. Insurance demand is also positively influenced by the yield's coefficient of variation and the loss ratio, and negatively influenced by proxies for wealth (including CAP subsidies) and activity diversification.

Keywords: Crop insurance, Pesticide use, Simultaneous equations.

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1 Introduction

In recent years, agricultural risk management has become a key issue of agricultural policy reforms. The context has indeed changed deeply. Price support policies[1], which provide farmers an economic safety net in addition to income support, tend to disappear under the pressure of world trade liberalization and environmental concerns, raising the issue of price risk management in a liberalized world (World Bank, 2005). At the same time, a substantial number of production risks due to climatic and phytosanitary hazards remain uninsurable without government support in favor of crop insurance (World Bank, 2005). Under free trade, production shocks are no longer compensated by rises in prices, a "natural hedge" of farmers' revenues that renders useless the need for crop insurance in autarky. The importance of climatic and phytosanitary risks as well as price volatility are thus calling for policy responses. The usual argument for risk policies in agriculture relies on the incompleteness of contingent claims markets that makes competitive markets inefficient in the short term. Such inefficiency provides a theoretical argument, in certain circumstances, for second-best Pareto improving government interventions that would mimic such absent contingent claims markets and restore the correct price incentives (Newbery and Stiglitz, 1981; Innes, 1990). In the long term, incomplete insurance and/or credit market lead to a too high, socially inefficient farm turnover, some viable agricultural firms being artificially unable to survive to temporary shocks (Kirwan, 2009). Despite these well-founded theoretical justifications[2], the consensus is far too be reached about the true costs and benefits of government crop insurance programmes that take place in real world. Crop insurance markets are usually plagued by various kinds of market failures, making the distinction between welfare-enhancing and redistributive objectives particularly uneasy. Since in developed countries crop insurance programmes often involve substantial financial support from governments, this raises the issue of "disguised subsidies". In addition to being highly controversial in terms of their pure risk-sharing benefits, it is frequently pointed out that

[1] through public storage in the European Union or Target Prices in the United States

[2] Such normative result must be qualified. Indeed, the welfare gains, eventually losses, from risk policies have been shown to be highly sensitive to changes in parameters, especially supply and demand elasticities (Newbery and Stiglitz (1981), Innes (1990)). More profound is the critics by Dixit, who considers that welfare gains coming from government interventions may be highly overestimated because classical models implicitly assume governments to be immune to the fundamental causes that make market collapse, such as moral hazard, adverse selection or imperfect observability

government risk management programmes (in particular crop insurance ones) may have adverse environmental consequences. In particular, they would incite farmers to produce more, on more degraded lands, by using higher levels of risk-increasing inputs such as fertilizers and selecting shorter crop rotations, the same crucial critics that were already addressed to the classical, price-support based, agricultural policies of the 70's-80's .

The United States provide an interesting illustration of this debate. In this country, government crop insurance programmes constitute after nearly three decades of existence a growing component, if not one of the building block of the Farm Bill. Crop insurance programmes take the form of a public-private partnership between the Federal Government, through the Risk Management Agency (United States Department of Agriculture) and private primary insurers. Government support include substantial premium subsidies, Federal Reinsurance of last resort and reimbursement of primary insurers' administrative costs. In spite of such financial support, provided through various channels, farmers' participation has always been low and difficult to boost, but recent increases in premium subsidies lead to reach a participation rate of nearly 80% (Glauber, 2004). Several empirical analysis of U.S. crop insurance programmes tend to show that crop insurance programmes have negative environmental consequences through the production distortions they create (Roberts et al., 2004). Moreover, a recent paper by Kirwan (2009) shows that the farm failure rate has increased by 1.7 percentage points (30 percents) after the 1994 Crop Insurance Reform Act, that replaced ad-hoc disaster reliefs by crop insurance subsidies as the major form of government intervention. Last but not least, expanded crop insurance programmes did not succeed in eliminating Disaster Bills, i.e. ad-hoc transfers made by the Federal Government to support farmers in times of financial distresses due to adverse climate shocks.

In the European Union, growing attention is also being paid to weather risks in agriculture in a context of profound reform of the Common Agricultural Policy (hereafter CAP). The European system differs from the U.S. one. Price risks are managed at the EU level through guaranteed prices while weather risks and crop insurance programmes, when they exist, are under the responsibility of Member States. Guaranteed prices have decreased due to CAP reforms and have been replaced by decoupled agricultural subsidies to support farm revenues, with an a priori ambiguous impact in terms of farmers' risk aversion (more risk due to less price protection but less risk aversion due to a wealth effect). This has lead Member States to assess the possibility of a crop insurance programme at the E.U. level (see the European project for a deeper analysis). Enlarging the perimeter of mutualization for risks that are considered as systemic at the National scale has undoubted some economic sense, but the lessons from the costly U.S. experience certainly incite regulators to prudence.

This paper deals with multiple risks decision making in agriculture by investigating the determinants of rapeseed hail crop insurance and pesticides uses, using an original panel data set of French farms covering the period from 1993 to 2004. We first propose a theoretical background, and then follow the reduced form approach and build an econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables to account for potential endogeneity, which we estimate.

Related literature.— The relation between production and insurance/hedging decisions is a central aspect of the welfare and redistributive impacts of crop insurance programmes. There is a large theoretical and empirical literature on farmers' choices involving risk that intend to estimate how risk preference do indeed affect farmers' production and financial choices, and how these choices interact (Just, 2000; Just and Pope, 2003). Most papers concern the U.S. case, in part because several reforms of Federal risk management programmes have stimulated empirical research on this topic. Garrido and Zilberman (2005), Ogurtsov et al. (2008) and Velandia et al. (2009) estimate the simultaneous demand for crop insurance and other risk management instruments (forward contracts, etc.) as a function of farms' characteristics. Another group of related papers focus on the relation between insurance and production choices, providing some empirical testing of the possible distorsive effects of risk management instruments (eventually magnified by public subsidies): Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged pesticide and fertilizer input uses for corn producers in the U.S. Midwest. This contrasts with Smith and Baquet (1996), whose estimations show that fertilizer and pesticide inputs for Kansas wheat producers tend to be negatively correlated with insurance purchases. Wu (1999) is the first to extend the analysis to acreage decisions as a risk diversification tool. In his estimation of the effect of crop insurance on crop acreage allocation and pesticide use in Central Nebraska Basins, he shows that crop insurance participation encourages producers to switch to crops in higher economic values. In a more recent paper, Goodwin et al. (2004) study the acreage effects of crop insurance using the samples of corn and soybeans production in the U.S. Corn Belt and wheat and barley production in Northern Great Plains. They estimate a simultaneous equation model to take into account a larger set of endogenous risk decisions of agricultural producers to simulate the possible effects of large premium changes. Their results suggest a relatively modest acreage responses to expanded insurance subsidies. In a very recent study on insurance and acreage decisions, O'Donoghue et al. (2009) conduct an empirical analysis of the interaction between specialization and the price of crop insurance, which has been lowered through an increase in Federal premium subsidies by the Federal Crop Insurance Reform Act. They found a statistically significant but small positive relation between the degree of specialization and the level of premium subsidies.

Two general conclusions can be drawn from the existing literature. First, risk management choices are generally endogenous, suggesting possible substitutions or complementarities between risk management instruments. Second, typical explanatory variables that may influence farmers' risk aversion such as yields' coefficients of variation, financial ratios (an imperfect measure of liquidity constraint), farmers' wealth, land ownership are most of the time statistically significant. This tends to support that risk do indeed matter in farmer's production decisions. Third, although statistically significant, some variables have in some cases a small quantitative effect (O'Donoghue et al., 2009), in other cases strong quantitative effects, suggesting prudence in drawing too general policy conclusions at the national scale. Four, results may be qualitatively contradictory and unexpected with regards to theoretical prediction, in particular the relation between insurance and input uses. Theory suggests that the demand for risk-reducing inputs should be lower for those who buy insurance than for those who do not buy because of a standard moral hazard effect. This moral hazard argument, which has been the cornerstone of empirical studies and discussions on the subject in the U.S.A, is particularly relevant in this country because of the nature of crop insurance policies. These are *multiple peril*, which means that they provide coverage against any source of yield risk, including pest risk, which is manipulable by the farmer. Theory predicts a negative relation between the demand for insurance and the consumption of risk-reducing inputs.

Preceding empirical studies[3], mainly based on U.S. data, did not lead to clear cut conclusions concerning the sign of the correlation between pesticide and insurance decisions[4], although the fact that both decisions are made *endogenously* are rarely challenged[5]. Since many producers' decisions involve risk considerations, it is difficult to build a theoretical model that would capture an exhaustive analysis of their interactions (Goodwin et al., 2004) and yield unambiguous results, even in a static model. The classical moral hazard framework does not include multiple sources of risks, adverse selection, price risk, which may be potential explanations of these contradictory results.

The current paper contributes to the existing literature in three ways. First, instead of relying on aggregated time-series or cross-section data as in most of previous studies, we use farm-level data. This is expected to provide us with a more precise description of individual decisions. Second, the current study uses panel data, which possess several advantages over conventional cross-sectional or time-series data sets, while exploiting genuinely observed regime transitions. At last, this paper contributes to the growing literature on the empirical analysis of risk management decisions in the case of France and other European countries (Koundouri et al., 2009; Mosnier et al., 2009).

This paper is organized as follows. Some key facts concerning cereal production, weather risks and crop insurance in France are described in Section 2. Section 3 presents the theoretical background of simultaneous input and insurance decisions. In section 4 we present the empirical model followed by a description of the data and estimation results. We conclude in section 5 with a summary of our results and research perspective.

[3] Another group of papers also deal with farmers' risk-taking decisions but differ in their econometric approach of the cited ones by building structural instead of reduced-form models. The advantage of such approach is to allow for simultaneous estimation of production technology parameters and risk preferences. Examples of papers fitting with this approach are Chavas and Holt (1996) and more recently and Koundouri et al. (2009) to evaluate the risk and wealth effects of agricultural policy changes towards decoupling in the European Union.

[4] Horowitz and Lichtenberg (1993) have found a positive correlation between crop insurance and chemical input usage for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical usage for Kansas wheat producers tended to be negatively correlated with insurance purchases. Wu (1999) and Goodwin, et al. (2004) suggest no clear relationship between crop insurance demand and input use.

[5] Using Hausman-Wu test, Goodwin et al. (2004), Smith and Baquet (1996) and Wu (1999) have found that insurance, crop mix, and chemical use decisions are not exogenous and should be estimated using a simultaneous equations approach.

2 Policy context for crop insurance in France

2.1 The French system before 2005: duality between private and public coverage

The French agricultural sector is characterized by production diversity at the national level and a high degree of regional specialization. Most of the French farms are specialized in a narrow set of crops. The main climate risks are frost, hail and drought. Frost and hail risks mostly concern wine-growing and arboricultural, while hail and drought are the first causes of crop losses for non perennial crops (cereals essentially). Like other countries aiming at stabilizing farmers' revenues, France is doted with a specific agricultural insurance system against agricultural climate risks, which can be described as follows. First, risks are classified in two categories: insurable and uninsurable. Insurable risks are covered by private markets without any government intervention (or a very limited one) while uninsurable risks are covered by a public guarantee fund, the *Fonds National de Garantie des Calamités Agricoles* (FNGCA), created by the law of 1964. Private and public coverage thus coexist without competing with each other. The "insurability" criteria are not explicitly defined in the law of 1964, although it states that the set of insurable risks is susceptible to evolve if the private sector becomes able to develop its own supply. The fund profoundly differs from private insurance market. First it is not financed by actuarially fair premiums, but by the mix of a mandatory contribution on farmers' property/liability insurance contracts and a government subsidy, with approximately an equal sharing between the two sources (the "parity principle"). Thus premiums are not risk based and government participation implies a positive redistribution, in average, from taxpayers to the farm sector. Second, indemnifications are upper-bounded by the amount available in the funds, and so are not contractually prespecified as it is the case in a typical insurance contract. Third, the fund pools several risks (drought, hail...) for several products (wheat, maize, fruits...) which without practicing risk-based premiums is a source of cross-subsidization across farms with different specializations (between maize producers and wine-growers, for example) since mandatory contributions are not actuarially fair. The system has clearly some advantages, notably the fact that mandatory participation implies a large pooling of diversified risks, but also defaults: premiums are not functions of risks, which is a source of distortional choices, and the levels of indemnifications are low, even with the presence of a large amount of government subsidies. Hence the paradox: if redistribution from taxpayers to farmers is positive in the mean, farmers often criticize the low levels of indemnifications (around 30% of expected losses are indemnified). Moreover farmers are not free to choose between different levels of coverage if they differ in their risk preferences and their opportunities to diversify risks.

2.2 The private crop insurance market in France

Until the reform of 2005, hail was the main risk covered by a private insurance market in France, i.e. without government subsidies nor government reinsurance of last resort interventions. Hail insurance contracts are proposed by several insurance companies specialized in financial products for the agricultural sector. The proposed contracts can be described as follows. Indemnities are provided when the final yield is under a threshold value, which is freely chosen by the producer as a percentage of his reference yield. The reference yield is the mean of the five preceding years, leaving apart the higher and the lower values. When no yield data is available for an individual producer (which can occur if he has never cultivated the crop), the mean departemental yield is used as a proxy. Some standardized values of deductibles are proposed, which are typically 5%, 10% and 15% of reference yields for cereals such as wheat and maize, and 10% and 15% for rapeseed. In addition to choosing their deductible, producers are free to choose the price at which they will be indemnified, up to a maximum price fixed by the insurer. The latter provides information about prices forecast to help farmers to make their choice. In case of yield losses, indemnifications are based on plots, not on the total farm output for the given product. Thus if total farm yield per acre is higher than the yield that triggers indemnifications but lower on a given plot, indemnifications will be made for this plot (this is not the case for other risks included in the package of the reform of 2005). In order to control for potential moral hazard problems, audits are made in order to verify that appropriate agricultural practices were followed, in particular the use of phytosanitary products. Since the crop insurance reforms initiated in 2006, private insurers now propose multiple risk insurance contracts that cover not only hail on a plot basis, but twelve new sources of climatic risks including drought, etc. on a mean farm yield basis. The basket of risks covered by these new insurance contracts can be chosen by the producer. Contrary to the traditional hail insurance contract, these contracts are now subsidized by the government at a rate of 35% of the premium.

2.3 The recent reforms: towards a public-private partnership?

The system has been reformed strongly in recent years. The reform of 2005 aimed at extending the set of insurable risks, i.e. risks covered by private insurers. Before this date, mainly hail risk was insured through the private market in a sustainable way without government support. The reform of 2005 introduced for the first time large scale premium subsidies in order to stimulate farmers' demand and incite private insurers to expand their agricultural insurance supply to a larger set of risks. Subsidized contracts are targeted to cereal producers and provide coverage against multiple risks, as in the United States (twelve risks including drought, frost etc.). After a few years of existence, participation is not negligible but still limited. Although it seems to be inspired by the U.S. system, important differences subsist. First, premium subsidies are considered as temporary. The underlying idea is to encourage learning on both supply and demand sides: on supply side, since insurers propose new contracts that may be susceptible of high financial exposure due to correlated risks (drought in particular); on the demand side since farmers were not used to making free choices before. Second, although the debate remains open, the French government does not play the role of reinsurer of last resort as in the U.S. system. The current trend of reforms provide strong justifications for empirical analysis of the role of risk in farmers' choices and welfare in France. Unfortunately, it is too early to study the impact of the reform of 2005, since our data set goes to 2004. Moreover, the first years of application are heavily driven by learning from both sides of the market, which renders any comparison uneasy to interpret. Thus our objective here is to study the relation between insurance and input decisions in the pre-reform period.

3 Theoretical background

We focus our study on two typical risk management instruments of farmers[6]: insurance and pesticides. The direct factors that affect the demand for insurance are the farmer's coefficient of risk aversion, the cost of insurance, and the characteristics of the insured risk such as the size of the risk and other characteristics of the risk probability distribution (Henriet and Rochet, 1991; Alarie et al., 1991). The optimal insurance coverage increases with risk aversion and the size of the risk, and decreases with the cost of insurance. Other factors influence the demand for insurance indirectly through their impact on the farmers' coefficients of risk aversion: wealth, the presence of one or several background risks (Eeckhoudt and Kimball, 1991), and the presence of a liquidity constraint (Gollier, 2001). Under the reasonable assumption of decreasing absolute risk aversion (DARA), risk aversion decreases with farmers' wealth, thus so does the optimal insurance coverage. The presence of an *exogenous* background risk increases the optimal insurance coverage if the agent displays prudence in the sense of Kimball. DARA itself implies prudence. For identical reasons, all the factors cited above are also susceptible to affect the use of risk-increasing and risk-reducing inputs such as pesticides.

Analyzing the farmers' choices of insurance and input uses also requires to take into account endogeneity between insurance demand and pesticide use. In the long run, pesticide uses and insurance demand are taken jointly in order to maximize the farmer's utility. Several papers examine the consequences of the introduction of a crop insurance contract on the firms' input uses (or the dual output decision). Machnes (1995), Gollier (1996) and Machnes and Wong (2003) consider a price-taking firm's simultaneous decisions of production and insurance coverage when yield is affected by.a multiplicative risk, i.e. proportional to the expected production; comparing the production decisions with and without insurance, they show that, under reasonable assumptions, in particular these of prudence, the optimal production level tends to increase after insurance is introduced[7]. Since multiplica-

[6] There is an absent risk management tool in our analysis. Because of unavailable data, price hedging decisions on futures markets have not been taken into account in the analysis. Since what matters to producers is income risk, and price risk is certainly not less important than production risk, incorporating price hedging into the set of risk management tools could have enriched the analysis.

[7] Gollier (1996) provides counterexamples. Machnes and Wong (2003) show the necessity of prudence to obtain unambiguous effect of deductible insurance on production. Such assumption was unnecessary in Sandmo (1971)'s underproduction result.

tive production risk is formally identical to price risk, this result recalls the traditional underproduction result of Sandmo (1971) obtained in a context of price risk. Ramaswami (1993) generalizes the analysis by considering a richer set of interactions between controllable inputs and climatic factors, considering both risk-reducing and risk-increasing inputs. He shows that the change in input use coming from the introduction of insurance can be decomposed into a *risk-reduction effect* and a *moral hazard effect*. The direction of these changes depend on the nature of the interaction between inputs and climatic factors. Hau (2006) extends the analysis by examining a single non-multiplicative risk[8]. Chambers and Quiggin (2000) propose a general state-space approach that allow for more tractable analysis of production insurance and hedging decisions under risk.

This literature shows that *gaining access* to insurance tends to modify input use but the direction of the change is ambiguous since it combines risk-reduction and moral hazard effects. Most of the U.S. empirical papers described in the introduction base their interpretation on the moral hazard effect, i.e. the fact that insurance participation tends to decrease the use of risk-decreasing inputs (pesticides). But as we have shown, qualitative results contradict each other. Moreover theoretical models of simultaneous insurance-pesticides decisions consider a single source of risk [9].

We now present the theoretical model that is the subject of our econometric estimation. The single risk framework does not fit well with the present case, since farmers of our sample face in fact not a single but two distinct risks: hail risk and pest risk, against which they use two independent risk management tools: hail insurance and pesticides. In order to take into account the presence of two risks, we extend the Just-Pope production function, which considers a single risk, by adding a multiplicative climate risk.

[8]The traditional approach in the literature has been to use a stochastic production function of the form $f(\mathbf{x}, \mathbf{e})$, where $\mathbf{x}$ is a vector of controllable inputs (fertilizers, pesticides etc.) and $\mathbf{e}$ a vector of environmental inputs (rainfall, moisture, temperature etc.) that are stochastic when $\mathbf{x}$ is chosen by the farmer. The two most used specifications assume a single input, single risk production: the multiplicative risk model, with $f(x, \tilde{\varepsilon}) = x\tilde{\varepsilon}$ and the Just-Pope model, with $f(x, \tilde{\theta}) = f(x) + h(x)\tilde{\theta}$, with $E\tilde{\varepsilon} = \bar{\varepsilon} > 0$ and $E\tilde{\theta} = 0$, x being a singleton.

[9]Moreover, this literature compares the situations “with” and “without” insurance and is therefore adapted to the analysis of an exogenous change in the insurance regime, such as the creation of a crop insurance programme by the government. The issue is however different in our region study : we analyze the simultaneous insurance and production decisions by farmers *for a given insurance regime* which has been stable during the period covered in our sample. Thus, some people insure while others do not, but everyone has access to insurance.

$$y(x, \tilde{\theta}, \tilde{\varepsilon}) = [f(x) + \tilde{\theta}h(x)]\tilde{\varepsilon} \tag{1}$$

where x is the input, $\tilde{\theta}$ the pest risk and $\tilde{\varepsilon}$ the climatic risk. These two risks are assumed to be statistically independent. This model includes the multiplicative risk model and the Just-Pope model as a special case, when $\tilde{\varepsilon} = 1$. We assume that risk $\tilde{\varepsilon}$ has a binary distribution $(q, (1 - l); (1 - q), 1)$ where q denotes the probability of loss and $l \in [0, 1]$ is a coefficient that measures the extent of the yield loss, considered as given (i.e. non manipulable). The pest risk $\tilde{\theta}$ is characterized by $E\tilde{\theta} = 0$. It is uninsurable but can be mitigated through the use of a self-insurance input x, which unitary cost equals c. We adopt the usual assumption that pesticides are risk-reducing inputs with decreasing returns to scale, which corresponds formally to $h'(.) \leq 0$ and $h''(.) \geq 0$ respectively. The climatic risk $\tilde{\varepsilon}$ can be covered by a private insurance contract denoted $[P(\alpha, x), \alpha]$, where $\alpha \in [0, 1]$ is the coverage rate and $P(\alpha, x)$ the insurance premium as a function of coverage and input choice. Hail insurance contracts are structured as follows. A reference yield is calculated as the last years mean yield excluding the worst and best year. Thus the reference yield is equal to the expected yield $(1 - ql)f(x)$. Insurance coverage α is then defined as the fraction of the reference yield. An indemnity equal to $\alpha(1-ql)f(x)-(1-l)[f(x)+\theta h(x)]$ is thus paid when a hail shock occurs [10], with probability q. Assuming the output price w non-stochastic, exogenous and normalized to unity, the insurance premium can be written as:

$$P(\alpha, x) = (1 + \lambda)q(\alpha(1 - ql) - (1 - l))f(x) \tag{2}$$

where $\lambda \geq 0$ is the usual loading factor, $\lambda = 0$ corresponding to the actuarially fair premium. With unit costs of input being equal to c and normalizing the output price to one, the stochastic farm's profit is equal to

$$\tilde{\pi}(x, \alpha) = \begin{cases} \alpha f(x) - cx - P(\alpha, x) & \text{with probability } q \\ f(x) + \tilde{\theta}h(x) - cx - P(\alpha, x) & \text{with probability } 1 - q \end{cases} \tag{3}$$

Moral hazard is not considered since it is controlled through audits. A risk-averse farmer whose preferences are characterized by the von Neumann-Morgenstern utility function $u(.)$

[10] θ is written without a tilde when it corresponds to realization of $\tilde{\theta}$

with the stochastic production function presented above solves the following programme:

$$\max_{\alpha,x} U(x,\alpha) = Eu[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] \tag{4}$$

The optimal choices x^* and α^* are given by the first-order conditions for input and coverage. When $\tilde{\theta} = 0$, the problem is reduced to the multiplicative risk case studied in the literature presented before. The introduction of $\tilde{\theta}$ complicates the analysis. The combination of a risk-reducing and multiplicative model has been analyzed by Liu and Black (2004) in their two-shock model, where the multiplicative risk is assumed to represent a price risk. They show that the introduction of insurance has ambiguous effects on input use when input is risk-decreasing. However, their framework is different than ours since the insurable risk corresponds to $\tilde{\theta}$ in our model. In our case, the presence of two independent risks can lead to a non-monotonic marginal effect of x on the reduction of variance. Appendix 6 studies this aspect in the case of mean-variance preferences.

In addition to insurance and pesticides, acreage decisions could also be considered as a risk management tool at the farm level. It is however assumed that acreage is long-term decision and so does not enter into the year-to-year multiple risk-taking decision of the farmer. This can be justified on technical grounds: switching from a rotation to another can incur costs (yield losses, fixed costs) as well as time lags. Moreover, the decision to diversify can be the result of expected profit maximization due to positive production externalities between crops, as analyzed by Hennessy (2006). From an agronomic point of view, these externalities come from nitrogen carry-over effects and/or reduction of pest infestations, and can be a way to maintain or increase the soil's production potential over time. To a certain extent, crop production externalities qualify the traditional view of acreage allocation as a standard portfolio problem, and thus the role played by risk aversion[11].

To sum up, it is generally recognized that pesticide not only reduce risk but also increase expected production, thus increasing exposure to the second, multiplicative risk. It seems to be intuitive that producers with higher expected production will tend to buy more

[11] There are other arguments for this qualification: the allocation of labor time across crops, the farmer's use of its own crop product for livestock, the impossibility to cultivate certain crops on a subset of plots because of soil quality.

insurance because the expected value of the output, and so the potential loss, is higher. The underlying economic mechanisms at stake in these interactions may however be quite different depending on the theoretical framework which is considered. The following section intents to estimate the joint demand for insurance and pesticides uses with an econometric model involving simultaneous equations.

4 Empirical model

4.1 Econometric model

We now turn to the econometric model in order to examine hail insurance and pesticide use decisions. Our data set does not include insurance coverage itself but insurance expenses, for each crop. The usual way in the literature is to consider the demand for insurance as a binary variable identifying whether the farmer participates or not (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996; Wu, 1999). This is a limitation of these studies which focus on the decision of insurance purchase only and not take into account the level of coverage in the analysis. In spite of absent data, we choose to approximate the demand for insurance by the premium per unit area divided by the mean product per unit area, i.e. crop yield times crop price, calculated on the total years available. Such normalization by the mean product allows to eliminate the mechanical increase in premium coming from an increase in the value of the insured output, as shown by equation (2) in the case of a linear transaction cost function.
Our approach follows the empirical literature on crop insurance and production decisions, such as pesticide use (Horowitz and Lichtenberg, 1993; Smith and Baquet, 1996), cultivation practices (Goodwin et al., 2004) and cropping patterns (Wu, 1999). We thus fit into the simultaneous equation approach framework. To investigate the determinants of crop insurance demand under endogenous input use decision, we estimate our model using individual farm panel data covering the period from 1993 to 2004 instead of the usual cross sectional dataset. Our dataset allows us to capture individual farmers effects and also to follow the evolution of farmers' choices over a long period of time. Panel data, by taking into account the inter-individual differences and intra-individual dynamics have several advantages over cross-sectional or time-series data. In our case the two most important

advantages[12] are to have more accurate inference of model parameters and to control the impact of farmer's individual heterogeneity.

Following theoretical analysis and the empirical literature, we consider in this analysis that the farmers's crop insurance and pesticide input use decisions are made simultaneously. Our econometric model thus corresponds to two simultaneous equations with a mixed censored/continuous dependant variables and panel data. The simultaneous equation system can be written as follows

$$I_{it}^* = X_{1it}'\beta_1 + P_{it}\gamma_1 + w_{1it}, \quad (5)$$

$$P_{it} = X_{2it}'\beta_2 + I_{it}^*\gamma_2 + w_{2it}, \quad (6)$$

and the observed counterpart is:

$$I_{it} = \begin{cases} I_{it}^* & \text{if } I_{it}^* > 0, \\ 0 & \text{otherwise.} \end{cases}$$

where I_{it}^* is the latent variable for the farmer's i insurance demand at time t, I_{it} is the observed demand insurance for the farmer i, P_{it} is the pesticide input demand of farm i at time t, X_{1it}' and X_{2it}' are vectors of explanatory variables, $\beta_1, \gamma_1, \gamma_2, \beta_2$ are parameters to be estimated,w_{1it} and w_{2it} are error terms, $i = 1, ..., N$ indexes the farmers and $t = 1, ..., T$ indexes time period of observation. The error term w_{mit} $(m = 1, 2)$ is decomposed as

$$w_{mit} = \mu_{mi} + \varepsilon_{mit}, \qquad m = 1, 2, \quad i = 1, ...N, \quad t = 1, ...T, \quad (7)$$

where μ_{mi} is the individual effect for the farm i and the variable of decision m and ε_{mit} is an i.i.d. error term for equation m.

We make the following distributional assumptions:

$$\mu_{mi} \hookrightarrow N(0, \sigma^2_{\mu_m}), \quad \varepsilon_{mit} \hookrightarrow N(0, \sigma^2_{\varepsilon_m}), \quad E(\mu_{mi}\varepsilon_{mit}) = 0, \quad \text{for all} \quad m = 1, 2, ..., M$$

with

$$E(\mu_{mi}\mu_{kj}) = \begin{cases} \sigma_{\mu_{mk}} & \text{if} \quad i = j, \\ 0 & \text{otherwise,} \end{cases}$$

[12] See Hsiao(2007) for a survey of advantages of Panel data.

$$E(\varepsilon_{mit}\varepsilon_{kjs}) = \begin{cases} \sigma_{\varepsilon_{mk}} & \text{if} \quad i=j \quad \text{and} \quad t=s, \\ 0 & \text{otherwise,} \end{cases}$$

for all $m,k = 1,2, \quad i,j = 1,...N, \quad$ and $\quad t,s = 1,...T.$

The model (5-6) has a mixed structure since it includes both a latent variable and its dichotomous realization. Procedures for estimating simultaneous equation models in which one or more equation contains limited dependent variable have been developed by Amemiya (1974), Amemiya (1979) and Nelson and Olson (1978). This literature shows that the FIML (Full Information Maximum Likelihood) is computationally difficult and may be infeasible. Nelson and Olson (1978) propose a simple two stage estimation procedure where endogenous variables are replaced by predicted values obtained at first stage by regression upon an instrument set. This two-step procedure has the advantage to give consistent estimates of the coefficients of the model, however Amemiya (1979) shows that this two-steps procedure misrepresents the true variances of parameters. Bootstrapping methods were proposed in the literature to estimate consistently the parameters of the matrix of variance covariance.

Following the literature, we estimate our model by a two-stage procedure (Maddala, 1983)[13]. In order to obtain consistent estimates of the parameters of the variance-covariance matrices we use bootstrap methods proposed by Efron (1979) and Efron (1987). The bootstrapping approach consists in drawing with replacement a large number of pseudo-samples of size N (which correspond to the number of observations in the observed data). For each sample the two-step procedure is applied in order to generate a distribution of consistently estimated parameters. Such an approach provides consistent variance-covariance parameter estimates that are robust to heteroscedasticity.

Since our sample consists of panel data, we have to choose between a random effect and a fixed effect specification. We assume a random effect model because the fixed effect specification suffers from the incidental parameters problem[14] in the case of Tobit model, Greene (2004) shows that the incidental parameters problem causes a downward bias in the estimated standard deviations in the Tobit model specification. Such problem might

[13]Our model corresponds to the model 2 in Maddala (1983).

[14]The incidental parameters problem of the maximum likelihood estimator in the presence of fixed effects (MLE/FE) was first analyzed by Neyman and Scott (1948) in the context of the linear regression model.

lead to erroneous conclusions concerning the statistical significance of the variables used in the regressions.

The first step of the two-stage procedure consists in estimating the reduced form of the system (5-6) which can be written as follows [15]:

$$I_{it}^{*} = X_{it}'\Pi_1 + \xi_{1it}, \quad (8)$$

$$P_{it} = X_{it}'\Pi_2 + \xi_{2it}, \quad (9)$$

where X_{it}' includes all the exogenous variables in X_{1it}' and X_{2it}'. This first step of the procedure provides us with estimates of the parameters Π_1, Π_2 as well as the matrix of variance covariance of individual effects and iid error terms. In our case, we estimate the equation in (8) by a random effect Tobit model and the equation in (9) by ML-RE model. In the second step, we estimate the equation (5) by RE-Tobit after substituting $\widehat{P}_{it}$ for P_{it} and the equation (6) by RE-ML after substituting $\widehat{I}_{it}^{*}$ for I_{it}^{*}. This two stage procedure gives consistent estimates of the model coefficients (Maddala, 1983), but the estimates of variance of the coefficients may be inconsistent because predicted values of the endogenous variables are used in the second stage of the estimation procedure.

Marginal effects.— Computation of elasticity measures requires calculation of marginal effects from the RE-Tobit model[16]. Given the censored nature of insurance demand equation different marginal effects can be computed for each explanatory variable. For each explanatory variable x_j, we have calculated at the mean of the sample, the three elasticities[17]:

1. Conditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand given that the farmer holds an insurance contract.

$$Ela_{conditional} = \frac{\partial \ln E(I|I>, x=\overline{x})}{\partial \ln x_j} = \beta_j \frac{x_j}{E(I|I>, x=\overline{x})} \quad (10)$$

[15]See the appendix 6.3 for more details.

[16]As proposed by Wooldridge (2002) the marginal effects were estimated by making the normalization of the individual-specific effects such as $E(\mu) = 0$.

[17]see Greene (2008).

2. Probability elasticity: which measure for each explanatory variable the elasticity of the probability that a farmer holds an insurance contract.

$$Ela_{proba} = \frac{\partial \ln Pr(I > 0|x = \overline{x})}{\partial \ln x_j} = \frac{\partial Pr(I > 0|x = \overline{x})}{\partial x_j} \frac{x_j}{Pr(I > 0)} \tag{11}$$

3. Unconditional elasticity: which measure for each explanatory variable the elasticity of the expected insurance demand

$$Ela_{unconditional} = \frac{\partial \ln E(I|x = \overline{x})}{\partial \ln x_j} = \beta_j \times Pr(I > 0|x = \overline{x}) \frac{x_j}{E(I|x = \overline{x})} \tag{12}$$

As we have

$$E(I|x = \overline{x}) = Pr[I > 0|x = \overline{x}] \times E[I|I > 0, x = \overline{x}], \tag{13}$$

we can easily show that for each explanatory variable, the total elasticity is the sum of the probability elasticity and the conditional elasticity:

$$Ela_{unconditional} = Ela_{conditional} + Ela_{proba} \tag{14}$$

4.2 Data description

The study is conducted on a sample of French farmers from the *Departement* of Meuse. Our data are provided by the Management Centre (*Centre de Gestion de la Meuse*). Our sample is an unbalanced panel observed between 1993 and 2004. We consider in this paper the most important crops in terms of cultivated area: rapeseed, wheat and barley. One interesting feature of our database is that it contains detailed information for each crop on major inputs: fertilizers (N, P, K), pesticide inputs (herbicides, fungicides, insecticides, and growth regulators) and insurance.

As shouwn in table 1, approximately 88% of farmers in our sample hold a hail insurance contract . This proportion remained almost constant over the observation period 1993-2004, varying between a minimum of 81.90% in 1993 and a maximum of 91.25% in 2002.

Summary statistics presented in table 2 show that on average the farmers who hold a rapeseed hail insurance contract had less CAP subsidies than farmers without hail insurance contract. They are also more specialized in rapeseed production and have less animal production revenues (related to their total revenues).

Table 1: Farms who hold a hail insurance contract

Year	Total number of farmers	% of farmers who hold hail insurance contract
1993	442	81.90%
1994	432	83.56%
1995	450	85.33%
1996	451	85.36%
1997	483	87.78%
1998	489	88.34%
1999	487	90.14%
2000	481	89.39%
2001	459	89.10%
2002	446	91.25%
2003	392	89.79%
2004	161	89.44%
Total	5173	87.55%

Table 2: Summary statistics

Variable	**Definition**	Insurance=0	Insurance=1
		Mean	**Mean**
		(std. dev.)	(std. dev.)
primassph_col	premium per unit area / mean yield	0	0.008
		(0)	(0.005)
col_pacph	CAP subsidies per ha	4.734	4.672
		(0.917)	(0.788)
sanim_produit	share of animal revenue	0.564	0.455
		(0.226)	(0.259)
scol_produit	share of rapeseed production	0.246	0.287
		(0.099)	(0.099)
loss_ratio	sum of indemnities / sum of premium	0.259	0.791
		(0.74)	(1.409)
ratio_liq	debts / assets	0.158	0.183
		(0.131)	(0.138)
ind_ferm	=1 if land renting	0.991	0.995
		(0.096)	(0.073)
puthf	percent of family labor	0.933	0.906
		(0.132)	(0.158)
cvrdt_col	CV of rapeseed yield	0.399	0.275
		(0.457)	(0.278)
col_laglnprix	log rapeseed lagged price	-3.166	-2.447
		(4.455)	(3.309)
sau	Total farm area	16593.073	19764.295
		(7645.564)	(9979.700)

4.2.1 Choice of explanatory variables

According to the literature and to our theoretical discussion, the demand for crop insurance and risk-reducing input could be influenced by farms' characteristics such as farm's diversification, wealth, and liquidity constraints. We hereafter construct some proxies for these variables as explanatory variables of insurance demand.

Diversification.— The degree of farm's diversification is expected to have a negative effect on insurance and pesticide demands since it can be considered as a substitute to insurance as a risk management instrument. We consider two forms of farm diversification: *crop diversification* which refers to the classical rotation choice, and *activity diversification* which refers to the relative shares of crop activities taken as a whole with other sources of farms' revenues, i.e. livestock in our sample. Several index provide consistent measures of the degree of diversification, namely the Herfindahl index and Theil index of entropy. With two activities only, relative shares in the farm's total output constitute a simpler measure of diversification. Computation of these index revealed that they are highly correlated. We thus choose to restrict to a single measure. Since we have only three crops and two activities (crop and livestock), we define crop diversification as the share of rapeseed in the total crop product (*scol_produit*) and activity diversification as the share of livestock in the total farm product (*sanim_produit*). Note that since livestock activity is assumed exogenous, the activity diversification index can also be interpreted as a wealth effect.

Wealth.— If farmers display decreasing absolute risk aversion, then wealthier farmers may perceive less of a need to insure. There is not any real consensus in the literature in building a proxy for wealth in similar studies (farms' net present values, size index such as land area). The following proxies for farmers' wealth are included.

Non-crop revenues. As livestock activities provide returns that are independent to crop ones, we can interpret the activity diversification index as a proxy for wealth in addition to a diversification one.

Farm size. Many studies in the literature include a measure of farm size as a proxy for wealth. It also captures the effect of size economies on the demand for insurance. We thus include the agricultural area (SAU) as an explanatory variable.

CAP income support. Agricultural income support policies are also a major part of farmers' revenues, and can therefore be a strong component of the farmers' wealth effect. Hence CAP subsidies are also included as a proxy of farmers' wealth(col_pacph) as an explanatory variable.

Financial characteristics.— Financial characteristics of the farm such as debt and liquidity constraints are strongly expected to affect insurance and input choices through their impact on farmers' risk aversion. More liquidity constrained farmers would insure more ceteris paribus. We have built the three following ratios in order to capture such liquidity constraint: the total debt ratio, the land debt ratio and the liquidity ratio ($ratio\_liq$). These three ratios are expected to have a positive effect on insurance and input uses. For the same liquidity constraint reason, farmers who rent land are expected to buy more insurance and use more pesticides because they are more leveraged (Wu, 1999). We thus include a rent index (ind_ferm).

Loss ratio.— The demand for insurance is expected to depend on the expected return from insurance (usually negative), which includes premiums and expected indemnities. To capture such factor, we use individual farmers' loss ratios ($loss\_ratio$), a variable that is equal to the total indemnities divided by total insurance premiums for the available years. Since our panel is unbalanced, differences due to catastrophic events that arise some years can be a source of bias between farmers (Goodwin, 1993). However, excluding these years from our analysis would also create some bias and weaken the analysis so we kept all available years in our sample. Heterogeneity in loss ratios can be due to by asymmetric information if farmers are more informed that insurers about the distribution of their yield risk. Goodwin (1993), Just et al. (1999) and more recently Goodwin et al. (2004) provided empirical evidence of the importance of such factor on the incentive to insure in the U.S. agricultural context.

Yield variation.— In order to catch the effect of crop risk on insurance and pesticides, we include as it is usually the case in the literature[18], the individual coefficient of variation

[18] See for example Goodwin et al. (2004).

of yield (*cvrdt_col*). Intuitively, a high coefficient of variation reflects a higher crop risk exposure, thus an incentive to get insured.

Labor composition.— Total labor includes hired labor and family labor. The composition of the total labor could give us an idea of the nature of farm management. We build an index, *puthf*, which is equal to the share of family labor in the total farm labor (Wu, 1999).

4.3 Estimation results

We estimate a simultaneous equation model of crop insurance demand and pesticide demand using the two-stage procedure proposed by Nelson and Olson (1978) with a bootstrapping method to estimate consistent parameters of the variance-covariance matrices. Estimations are made on rapeseed only because this crop exhibits the higher coefficients of variation than wheat and barley.

Are insurance demand and pesticide use endogenous? The Durbin-Wu-Hausman test.— To test the simultaneous equation specification adopted in our model, the Durbin-Wu-Hausman[19] test was performed to test the hypothesis that: (1) crop insurance decisions are exogenous to pesticide input demand and (2) pesticide input demand is exogenous to crop insurance decisions. Results of these tests are presented in table 3 and show that the exogeneity hypothesis is rejected for the variable pesticide input in the insurance demand equation and for the insurance demand in the pesticide input equation. These results suggest that the two variables pesticide input and insurance demand are simultaneously determined. This result shows that insurance and pesticides choices are made jointly and thus provides a strong reason for our simultaneous equation model.

Model estimation.— The estimation results are presented in Tables 4 and 5. Table 4 displays the insurance model as a function of our explanatory variables and 5 displays the pesticide choice equation. As can be seen by inspecting the results the significant variances

[19]The "Durbin-Wu-Hausman" (DWH) test is numerically equivalent to the standard "Hausman test" obtained using in which both forms of the model must be estimated. Under the null hypothesis, it is distributed Chi-squared with m degrees of freedom, where m is the number of regressors specified as endogenous in the original instrumental variables regression.

Table 3: Durbin-Wu-Hausman test results

Null Hypothesis	DWH statistic	DF	Test result
crop insurance demand is exogenous to pesticide use	14.05	7	Rejected at 5% level of confidence
pesticide use is exogenous to crop insurance demand	19.43	9	Rejected at 2% level of confidence

of individual random effects confirms the advantage of using panel data and modeling individual effects. We conclude that the classical regression model with one single constant term is inappropriate and that there exist in the data individual heterogeneity captured by individual random effects. The elasticities $Ela_{unconditional}$,$Ela_{conditional}$ and Ela_{proba} (equations 10-12) are computed at the means of all variables and are presented in Table 6. The significant variables in Table 4 also have significant marginal effects (elasticities) in Table 6.

Concerning the parameters estimates, a first important result is that the quantity of pesticides (*col_qphytophhat*) used by farmers increases with the demand for insurance (*primassph_col*). Moreover, the demand for insurance increases with pesticides. As we have noted earlier, the empirical literature provided no consensus on the sign and magnitude of the effects on insurance on pesticide demand. Horowitz and Lichtenberg (1993) results suggest that crop insurance has encouraged the chemical input usage for corn producers in the U.S. Midwest. However, Smith and Goodwin (1996) demonstrated that fertilizer and chemical usage for Kansas wheat producers tended to be negatively correlated with insurance purchases. That means that the insured Kansas wheat producers tend to use less chemical input than the non-insured ones. Wu (1999)) has focused on the effect of crop insurance on crop patterns and chemical use in Central Nebraska Basins. The results show that crop insurance participation encourages producers to switch the crops in higher economic values. Thus, the expected relationship between insurance participation and input usage is unclear. The results of Goodwin, et al. (2004) suggest a relatively modest acreage responses to the increases in crop insurance participation.

Our estimation results concerning the effects of diversification on insurance demand are in line with our expectations. The variable *scol_produit*, which measure the share of rapeseed in total crop production has a positive and significant effect on insurance demand. This means that farmers that planted more rapeseed are less diversified and need more crop insurance protection. In the same way, the variable *sanim_produit* which measure the share of livestock activities in the farm revenue has a negative and significant effect on insurance demand. This confirm the fact that activity diversification reduce risk aversion and so insurance demand of farmers. Wu (1999) and O'Donoghue et al. (2009) find a statistically significant negative effect of crop diversification on crop insurance demand. Concerning activity diversification, Goodwin (1993) does not find a statistical negative relationship between the extent of diversification into livestock and the tendency to insure. Results concerning diversification must be interpreted with caution. Indeed, a negative correlation can be explained by a substitution effect between risk management tools, but a positive correlation, if arises, can be explained by heterogeneity in farmers' risk aversion: ceteris paribus, more risk averse farmers would diversify more, buy more insurance and use more risk-reducing inputs. Therefore, which of these effects dominates is likely to depend on the particular application and data set.

As expected, the CAP subsidies *col_pacph* have a negative and significant effect on the insurance demand, which can be interpreted as a wealth effect. The effect of direct payments on farmers' risk preferences has been recently estimated by Koundouri et al. (2009) using a structural model to estimate simultaneously risk preferences and technology parameters. Direct payments were shown to substantially decrease farmers' degrees of risk aversion.

Estimation results show that a higher yield coefficient of variation of rapeseed (*cvrdt_col*) appears to be positively and significantly correlated with greater demand for insurance. Such a positive relationship is conform to the intuition. However, the coefficient of variation is in part endogenous due to input uses (in particular pesticides) and crop diversification. For example, more risk averse farmers could insure more against hail risk while using more pesticides to reduce pest risk, and so exhibit a lower coefficient of variation of yield, calling for cautious interpretation.

The parameter estimate on the composition of total labor ($puthf$=family labor /professional labor) has the expected sign but is statistically insignificant at 10%. As expected, land ownership also affect farmers' insurance decisions ind_ferm. Farmers who rent land tend to exhibit a higher demand for insurance.

Another interesting but not surprising result is that higher loss ratio is significantly and positively correlated with greater demand for insurance. As discussed in Goodwin et al. (2004), the fact that both higher loss ratios and higher yield coefficients of variation are positively correlated with insurance demand suggest that the cost of insurance as well as size of the risk reduction do indeed matter in farmers' insurance decision. Finally, the parameter estimates of the liquidity ratio *ratio_liq* has the expected sign but is not significant.

Table 4: Rapeseed insurance demand

	primassph_col
col_qphytophhat	0.00344***
	(5.34)
col_pacph	-0.000211*
	(-2.04)
sanim_produit	-0.00312***
	(-4.13)
scol_produit	0.00218*
	(2.32)
loss_ratio	0.000664**
	(2.96)
ratio_liq	-0.000857
	(-0.93)
ind_ferm	0.00360***
	(3.67)
puthf	-0.000660
	(-1.31)
cvrdt_col	0.00838***
	(6.49)
_cons	-0.00348
	(-1.74)
sigma_u	0.00811***
	(12.08)
sigma_e	0.00317***
	(22.85)
$(N \times T)$	5127

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Marginal effects.— We now compute elasticities to get some insight about the magnitudes of the relations between variables. The results are presented in Table 6. First, we note that this magnitude is quite small concerning the relation between insurance and pesticides: the probability to buy insurance increases by 0.026% when pesticide use in-

Table 5: Rapeseed pesticide use

	col_qphytoph
primassph_colhat	4.850*
	(2.00)
col_laglnprix	0.0105***
	(5.27)
sau	0.00000445***
	(5.03)
ann3	-0.296***
	(-15.74)
ann4	-0.129***
	(-7.99)
ann5	0.0220
	(1.25)
ann6	-0.0638***
	(-4.07)
ann11	0.108***
	(4.55)
_cons	1.575***
	(66.19)
$(N \times T)$	5127

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

creases by one percent. Unconditional elasticity, which sums up the probability to buy insurance with insurance demand when positive, is equal to 0.056 %. Such figures should be interpreted cautiously since they may be the result of several effects, some of them acting in opposite directions: the moral hazard effect, which predicts a negative relationship between insurance demand and pesticide use, and the risk reduction effect, which predicts a positive one. In the present region study, it seems however reasonable to think that the moral hazard effect is not very important in practice because of the presence of insurers' auditing concerning input uses. Moreover, the fact that the insured risk displays low geographical correlation at the departement level, the perceived probability of being audited by farmers may be sufficiently high to deter the moral hazard incentive. The positive, although quite modest, elasticity value of pesticide use and provides some support to the risk reduction effect of insurance.
Heterogeneity in farmers' risk aversion can also explain such positive correlation but is unobservable. In this case, a low value for elasticity could be explained by unobservable heterogeneity in pesticide productivity. Indeed, pesticides not only reduce risk but also increase expected yields. The latter motive may be predominant in farmers' pesticide use decisions, explaining low values of elasticities.

These elasticity results shed some light on the complex interaction between insurance and pesticide choices at the farm level. Although the estimated figures seem to be small, they may be the result of countervailing incentives and/or unobservable heterogeneity. Therefore making predictions about the consequences of crop insurance reforms in France on pesticide uses should take these limits into consideration. During the period 1993-2004, available private insurance contracts protected against hail risk only. Other production risks such as drought were managed through the public fund FNGCA. Expanding the number of risks insured by private insurance contracts would give farmers more freedom to choose their combination of risk management tools at the farm level. This may increase the magnitude of the relation between insurance demand and pesticides.

We now discuss the other factors affecting insurance demand. Classifying them with respect to the value of the probability elasticity and unconditional elasticity in decreasing order, we get 1. the rent index (ind_ferm, 0.140 and 0.305 respectively), 2. the yield's coefficient of variation , 3. CAP subsidies per ha , and , 4. activity diversification and 5. the loss ratio.

The values of elasticities for the yield's coefficient of variation (*cvrdt_col*, 0.117 and 0.255) confirms the role of farmers' heterogeneity in risk exposure on insurance demand.

The other explanatory variables have interesting consequences for agricultural policy. First, CAP subsidies (*col_pacph*) have a negative but quite small impact on the probability to insure (-0.088), but a rather high one on total insurance demand (-0.192). This suggests that the wealth effect due to farmers' income support plays a non-negligible role in reducing the consequences of income shocks due to weather events. If such income support decreases due to forthcoming CAP reforms, farmers of our sample would be more disposed to increase their demand for risk-management tools such as insurance against weather events.

Estimated elasticities for activity diversification (*sanim_produit*) have the same order of magnitude than these for CAP subsidies (-0.074 and -0.161), suggesting that income diversification is also a substantial substitute for crop insurance in our region study.

Estimated elasticities for loss ratios (*loss_ratio*), considered as a proxy for the cost of insurance, are rather small (0.023 and 0.049 respectively). This suggests that a crop insurance policy based on premium subsidies should not lead to strong changes in insurance demand against hail risk. These results are in line with similar studies in the United States. In this country, only large levels of premium subsidies allowed to increase the rate of penetration of insurance at the national scale. Moreover, in many cases expected indemnities are higher than premiums, rendering insurance contracts valuable even for risk-neutral producers. The situation is quite different in France, where hail insurance is a "mature" market, with a large rate of penetration rate and decades of existence without any government subsidy (the average loss ratio of our sample is 0.791). Hence it is not so surprising that the impact of a change in the cost of insurance has modest effects on insurance demand. Intuitively, such impact could be more substantial for multiple peril crop insurance contracts, introduced through a public-private partnership in France in 2005, since they provide coverage against an extended set of risks, some of them displaying strong spatial correlation, hence higher premiums. From a theoretical perspective, shows that a risk-averse individual[20] always insurance against a low probability-high loss event if he buys

[20] In fact, any individual having preferences that display the second-order stochastic dominance property.

insurance for any other risk having the same expected loss. This suggests that crop insurance contracts extended to low frequency risks (typically drought) would always be bought by farmers who already have a hail insurance contract under identical transaction costs. However several factors are susceptible to curb insurance demand for this extended set of risks. First, these risks may not only differ in their distribution but also in their transaction costs. Insurance premiums are more difficult to calculate for less frequency risks, and spatial correlation as well as ambiguity may imply premium overloading by insurers. Second, there is substantial empirical evidence that shows individuals are reluctant to buy insurance against low probability events, or even do not consider at all risks under a certain probability threshold. At last, the insurance decision requires processing information and learning, so emerging insurance contracts may require a time lag for adaptation.

Table 6: Marginal effects: elasticities at the sample mean

x_j	$\frac{\partial \ln E(I\|x=\overline{x})}{\partial \ln x_j}$	$\frac{\partial \ln E(I\|I>0,x=\overline{x})}{\partial \ln x_j}$	$\frac{\partial \ln P(I>0\|x=\overline{x})}{\partial \ln x_j}$
col_qphytophhat	0.056**	0.030**	0.026**
	(2.36)	(2.35)	(2.36)
col_pacph	-0.192***	-0.104***	-0.088***
	(-5.77)	(-5.76)	(-5.67)
sanim_produit	-0.161***	-0.087***	-0.074***
	(-4.40)	(-4.43)	(-4.32)
scol_produit	-0.023	-0.012	-0.010
	(-0.84)	(-0.84)	(-0.84)
loss_ratio	0.049***	0.026***	0.023***
	(3.75)	(3.76)	(3.71)
ratio_liq	0.004	0.002	0.002
	(0.35)	(0.35)	(0.35)
ind_ferm	0.305**	0.164**	0.140**
	(2.29)	(2.29)	(2.29)
puthf	-0.079	-0.043	-0.037
	(-1.49)	(-1.49)	(-1.49)
cvrdt_col	0.255***	0.138***	0.117***
	(13.34)	(13.75)	(11.81)

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5 Conclusion and discussion

This paper investigates the determinants of hail insurance and pesticide use decisions using an original panel dataset of French farms covering the period 1993-2004. Statistical tests show that the pesticide use and insurance demand are endogenous to each other and simultaneously determined. An econometric model involving two simultaneous equations with a mixed censored/continuous dependent variables is then estimated.

The results of our estimation are twofold. First, it is confirmed that insurance demand has a positive effect on pesticide use and vice versa, providing empirical support for the interdependence of technical choices and insurance decisions. However, it is also shown that the magnitude of this relation, measured by elasticities, is quite small. Several explanations are proposed for this result: the presence of countervailing incentive effects of insurance (risk reduction and moral hazard), the ambiguous role of risk-decreasing inputs on the variance of yield, or the preponderance of the expected profit motive versus the risk-reducing one in pesticide use decisions by farmers. From an environmental policy perspective, this suggests that reforms aiming at facilitating the access to insurance against an expanded set of risks or reducing the cost of insurance may have positive but modest effects on pesticides use. With monoperil hail insurance contracts, moral hazard temptations concerning the use of pesticides may be more easy to control than for multiperil crop insurance contracts, for two reasons. The first one is that estimating the relative impact of pest and climate shocks on the final yield may be more difficult when multiple climate shocks enters the insurance contract. Another problem associated with multiple peril insurance contracts is that increasing the number of covered peril could possibly increase correlation across individual claims (drought), thus lower the probability of audit.

Second, the analysis of the explanatory factors of insurance demand confirm some theoretical predictions and have interesting consequences for agricultural policy analysis. CAP subsidies have been shown to have a statistically significative and negative influence on insurance demand, and in turn on pesticide use. This is in line with the assumption that farmers' preferences are characterized by decreasing absolute risk aversion, confirming results of several other studies in France and abroad. From an agricultural policy perspective, this suggests that decrease in CAP subsidies would increase the farmers' propensities to pay for risk management instruments, underlying the need for an integrated approach between income support and risk management policies in this sector. Activity diversification has also a statistically significant and negative influence on insurance demand, which confirms the assumption that whole-farm diversification is a substitute to insurance and risk-reducing inputs. More surprising is the fact that crop diversification is not statistically significant. This suggests that diversification is more an issue at the whole-farm level than at the crop acreage level. This points out interesting questions in terms of environmental policy in the agricultural sector. Indeed, our results suggest that encouraging crop rotations against monoculture would have no statistically significant impact on the intensity of pesticide use per hectare. Crop rotations thus may be chosen for other reasons than risk. They can be more profitable in expectation due to positive external effects between crops that follow each other, or be the result of other constraints such as soil qualities, which are not included in our data set. Our results show that farmers with riskier yields tend to buy more insurance, which is in line with theoretical predictions. The loss ratio, has a significant effect but of small magnitude on insurance demand, suggesting a low price elasticity of demand for insurance. Crop insurance premium subsidies could thus have small impacts on insurance demand. However, it should be noted that the insurance contracts that are analyzed in the present study are not the same than those that are actually subsidized in France, which cover multiple risks. Finally, we have shown that financial ratios are not statistically significant, which is also surprising.

Future challenges.— The results of this study could be enhanced and continued in several ways.

First, we do not consider price risk in our analysis. This is clearly a shortcut since theory suggests that production and insurance decisions are distorted when prices risk is introduced. Moreover, the CAP reforms of the 90's and beginning of 2000's significantly decreased price floors for major crops in the European Union, leading to a potential increase of real or perceived price risk for farmers. However, futures and forward markets were also available in France during the period covered by our sample, allowing farmers to transfer price risks to financial markets and so significantly reduce the importance of price risk. Unfortunately, farmers' positions on futures and forward markets are not available in our database, preventing us to include price hedging decisions in our analysis.

Second, our data concerning phytosanitary products are aggregate expenses, which include a set of specific inputs targeted to different sources of risks (moisture, etc.). It is possible that some producers are more exposed to some specific risks that are more costly to self-insure than others. We have assumed a continuous relation between the quantity of pesticides used (measured by the expenses) and the magnitude of loss reduction. In reality, the timing of application may be also determinant, so equal applied quantities with different fractioning can lead to different results in terms of loss reduction, but these actions are not observable. Phytosanitary (as well as fertilizer) decisions have in fact a dynamic nature, which can include observation and learning by the producer. Such ingredients would suggest a more subtle theoretical framework but is out of the scope of this paper.

Third, we foresee to carry out estimations by generalizing this exercise to the two major crops in the sample: wheat and barley, as well as considering the simultaneous demands for insurance for the three crops and including fertilizers in our analysis. This would allow to generalize our analysis of multiple risks management by farmers.

Fourth, it would be interesting to build a structural model that would allow joint estimation of technology and preferences. This requires to deepen the theoretical analysis of the joint demand for insurance and pesticides with two independent risks. This would allow us to confirm our results concerning the shape of farmers' preferences as well as making useful comparisons with results obtained elsewhere, in particular Mosnier et al. (2009) in the French case.

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6 Appendix

6.1 Theoretical model

In order to get some insights about basic intuitions concerning the role of pesticides, let us consider the case of a quadratic utility function:

$$u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma(\tilde{W}_0 + \tilde{\pi}(x,\alpha))^2$$

where a, b and γ are parameters such that $b+\gamma(\tilde{W}_0+\tilde{\pi}(x,\alpha)) > 0$. The farmer's preferences display risk aversion if $\gamma < 0$ (respectively risk loving if $\gamma > 0$ and risk neutrality if $\gamma = 0$). Under such specification, expected utility can be written as a function of expected wealth and the variance of wealth only. Indeed,

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))^2$$

i.e.

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = a + b\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)) + 0.5\gamma\big[(\mathbf{E}\tilde{W}_0 + \tilde{\pi}(x,\alpha)))^2 + \mathbf{Var}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))\big]$$

Thus expected utility can be rewritten as a non-linear function of these two arguments, $z(.,.)$

$$\mathbf{E}u[\tilde{W}_0 + \tilde{\pi}(x,\alpha)] = z\big[\mathbf{E}(\tilde{W}_0 + \tilde{\pi}(x,\alpha)), \mathbf{Var}(\tilde{W}_0 + \tilde{\pi}(x,\alpha))\big]$$

To keep things simple, assume that $\tilde{W}_0 = 0$ and that insurance is unavailable, i.e. $\alpha = 0$. With our production function specification involving two risks, expected profit and the variance of profit can be written as, respectively,

$$\mathbf{E}y(x,\tilde{\theta},\tilde{\varepsilon}) = \bar{\varepsilon}f(x)$$

and

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \sigma_{\varepsilon}^2[f(x)]^2 + \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2$$

Proof.

Computing expected yield, we get

$$\mathbf{E}y(x,\tilde{\theta},\tilde{\varepsilon}) = \bar{\varepsilon}f(x) + \mathbf{E}(\tilde{\varepsilon}\tilde{\theta})h(x)$$
$$= \bar{\varepsilon}f(x) + \big(\mathbf{E}(\tilde{\varepsilon})\mathbf{E}(\tilde{\theta}) + \mathbf{Cov}(\tilde{\varepsilon},\tilde{\theta})\big)h(x) \tag{15}$$

Since by assumption $\mathbf{E}(\tilde{\theta}) = 0$ and $\mathbf{Cov}(\tilde{\varepsilon},\tilde{\theta})$ ($\tilde{\varepsilon}$ and $\tilde{\theta}$ being two independent random variables), we thus get that

$$\mathbf{E}y(x,\tilde{\theta},\tilde{\varepsilon}) = \bar{\varepsilon}f(x)$$

Turning to the variance of yield, we have

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \mathbf{Var}[\tilde{\varepsilon}f(x) + \tilde{\varepsilon}\tilde{\theta}h(x)]$$
$$= \mathbf{Var}(\tilde{\varepsilon}f(x)) + \mathbf{Var}(\tilde{\varepsilon}\tilde{\theta}h(x)) + 2\mathbf{Cov}(\tilde{\varepsilon}f(x),\tilde{\varepsilon}\tilde{\theta}h(x)) \tag{16}$$

We consider each term of this sum:

$$\mathbf{Var}(\tilde{\varepsilon}f(x)) = \sigma_{\varepsilon}^2[f(x)]^2 \tag{17}$$

$$\mathbf{Var}[\tilde{\varepsilon}\tilde{\theta}h(x)] = \big\{\mathbf{E}(\tilde{\varepsilon}^2\tilde{\theta}^2) - [\mathbf{E}(\tilde{\varepsilon}\tilde{\theta})]^2\big\}[h(x)]^2$$
$$= \big\{\mathbf{E}(\tilde{\varepsilon}^2)\mathbf{E}(\tilde{\theta}^2) + \mathbf{Cov}(\tilde{\varepsilon}^2,\tilde{\theta}^2) - [\mathbf{E}(\tilde{\varepsilon})\mathbf{E}(\tilde{\theta}) + \mathbf{Cov}(\tilde{\varepsilon},\tilde{\theta})]^2\big\}[h(x)]^2 \tag{18}$$

We know that $\mathbf{E}(\tilde{\theta}) = 0$. Moreover, the fact that $\tilde{\varepsilon}$ and $\tilde{\theta}$ being two independent random variables implies that $\mathbf{Cov}(\tilde{\varepsilon},\tilde{\theta}) = 0$ and $\mathbf{Cov}(\tilde{\varepsilon}^2,\tilde{\theta}^2) = 0$. Hence this expression reduces to

$$\mathbf{Var}[\tilde{\varepsilon}\tilde{\theta}h(x)] = \mathbf{E}(\tilde{\varepsilon}^2)\mathbf{E}(\tilde{\theta}^2)[h(x)]^2$$
$$= \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2 \tag{19}$$

Hence we get

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \sigma_{\varepsilon}^2[f(x)]^2 + \sigma_{\theta}^2(\sigma_{\varepsilon}^2 + \bar{\varepsilon})[h(x)]^2 \tag{20}$$

End of proof.

The farmer's input choice is thus given by the following programme:

$$\max_x U(x,0) = z\big[\bar{\varepsilon}f(x) - cx, \sigma_\varepsilon^2[f(x)]^2 + \sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}^2)[h(x)]^2\big] \tag{21}$$

Assuming an interior solution, the optimal choice of input use, x^* is given by the first-order condition

$$\bar{\varepsilon}f'(x^*)z_1 - \big\{\sigma_\varepsilon^2 f'(x^*)f(x^*) + \sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}^2)h'(x^*)h(x^*)\big\}z_2 = c \tag{22}$$

Looking at the first-order condition, we see the double impact of a marginal increase in x on the variance of yield. On the one hand, since by assumption $h'(.) \leq 0$ it reduces the farmer's exposure to risk $\tilde{\theta}$ (risk-decreasing input). On the other hand it increases the exposure to the other risk, $\tilde{\varepsilon}$. Without further specifications of f and h and imposing conditions on the values of the parameters σ_ε^2 , σ_ε^2 and $\bar{\varepsilon}^2$, there is no clear cut conclusion on the fact that a marginal increase in x increases or reduces the variance of yield. For some values of parameters, the variance of yield can be a non-monotonic function of x. For small x, the variance decreases, and up to a certain level of x, it increases. This is explained by the relative strengths of the risk-reduction effect of x on $\tilde{\theta}$ and its risk-increasing effect on $\tilde{\varepsilon}$. To see this, consider the following specifications: $f(x) = k_1\sqrt{x}$ and $h(x) = \frac{1}{1+k_2 x}$ where k_1 and k_2 are two positive parameters. Computing the variance as a function of x, we obtain:

$$\mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})] = \sigma_\varepsilon^2 k_1^2 x + \sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})\frac{1}{(1+k_2x)^2}$$

Thus we get

$$\frac{\partial \mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})]}{\partial x} = \sigma_\varepsilon^2 k_1^2 - \frac{k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})}{(1+k_2x)^3}$$

and

$$\frac{\partial^2 \mathbf{Var}[y(x,\tilde{\theta},\tilde{\varepsilon})]}{\partial x^2} = \frac{3k_2^2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})}{(1+k_2x)^3} \geq 0$$

Hence the variance is convex in x. The sense of variation depends on the values of parameters. More precisely, if $\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}) \geq 0$, then the variance is increasing with on the interval $[0, +\infty[$. If $\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}) < 0$, the variance is decreasing on the interval $[0, \sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon})[$ and increasing on the interval $[\sigma_\varepsilon^2 k_1^2 - k_2\sigma_\theta^2(\sigma_\varepsilon^2 + \bar{\varepsilon}), +\infty[$. In the latter case, for small values of x, the ris-reduction effect dominates while for higher values the risk-increasing effect dominates due to the fact that x increases the production scale. Thus the effect of x on the variance of yield is non-monotonic.

6.2 Review of empirical results: synthesis

6.2.1 Part 1

Study	Assumptions	Region/Data	Main results
Horowitz and Lichtenberg (1993)	• “Moral hazard” • “Pesticides can be strongly risk-increasing” • “Crop insurance decision made before input use decision”	U.S. Midwest	• “Producers who purchased insurance applied 20% more N per acre and spent 22% more on pesticides”
Smith and Goodwin (1996)	• “Moral hazard” • “Crop insurance decision made simultaneously with input use decisions”	Kansas (dryland wheat farmers)/ Farm-level data	• “Crop insurance reduces input use” • “Each dollar spent on chemical inputs lowers the probability of insurance purchases by about 1%.”
Wu (1999)	• Substitution between risk management tools • Moral hazard	Nebraska/farm-level data	• “Farmers grow more corn and soybeans and less hay and pasture.” • “Crop mix changes lead to to 20% increase in N use, 33% increase in P use, and 22% increase in atrazine use.”

6.2.2 Part 2

Keeton et al. (1999)	-	"U.S., crop reporting district data"	• "45 million acres brought into production (including 30 million CRP acres) • "No environmental measures"
Nimon and Mishra (2001)	• "Moral hazard" • "Crop insurance decision made simultaneously with input use decision"	17 U.S. states, Agricultural Resource Management Study 1998 data/Individual data	• "Crop insurance increases pesticide use" • "Crop insurance reduces fertilzer use"
Goodwin et al. (2004)	Crop insurance influences acreage decisions	U.S. Corn Belt (corn and soybean) and Upper Great Plains (wheat and barley)/Farm level data	• A 30 % decreases in premiums increases acreage by 0.2-1.1 %. Significant but small impact.

6.3 Econometric model

$$\begin{aligned} I^*_{it} &= X'_{1it}\beta_1 + P_{it}\gamma_1 + w_{1it}, && (23)\\ P_{it} &= X'_{2it}\beta_2 + I^*_{it}\gamma_2 + w_{2it}, && (24)\end{aligned}$$

Then,

$$\begin{aligned} I^*_{it} &= X'_{1it}\beta_1 + (X'_{2it}\beta_2 + I^*_{it}\gamma_2 + w_{2it})\gamma_1 + w_{1it} && (25)\\ P_{it} &= X'_{2it}\beta_2 + (X'_{1it}\beta_1 + P_{it}\gamma_1 + w_{1it})\gamma_2 + w_{2it}, && (26)\end{aligned}$$

$$\begin{aligned} I^*_{it} &= X'_{1it}\widetilde{\beta_1} + X'_{2it}\widetilde{\beta_2}\gamma_1 + w_{2it}\widetilde{\gamma_1} + \widetilde{w_{1it}} && (27)\\ P_{it} &= X'_{2it}\widetilde{\beta_2} + X'_{1it}\widetilde{\beta_1}\gamma_2 + w_{1it}\widetilde{\gamma_2} + \widetilde{w_{2it}}, && (28)\end{aligned}$$

where $\widetilde{\beta_k} = \frac{\beta_k}{1-\gamma_1\gamma_2}$ and $\widetilde{w_{1it}} = \frac{w_{kit}}{1-\gamma_1\gamma_2}$, for $k = 1, 2$.